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Measurements of NO_x precursor concentration profile above the bed at a full scale W-t-E plant and the effect of precursor speciation on the NO_x formation

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Introduction

Satisfactory result from CFD modelling of NO_x formation during combustion of waste in grate-fired waste-to-energy plants relies heavily on an accurate description of the temperature field in the free-board, this is a consequence of the high dependency of the temperature on the fuel NO_x chemistry [1,2]. Modelling of the temperature field in the free-board in a CFD code relies on an accurate determination of the boundary conditions from the bed into the computational domain, e.g., species concentrations, gas temperature and gas velocity. Most CFD models of grate-fired waste-to-energy plants use a stand-alone model of the bed, describing the waste devolatilisation and the partial oxidation of volatiles, which have been coupled with the CFD model. The drying, devolatilisation and volatile oxidation in the bed is strongly coupled with the combustion of gaseous species in the free-board due to the radiation onto the bed as indicated in figure 1.

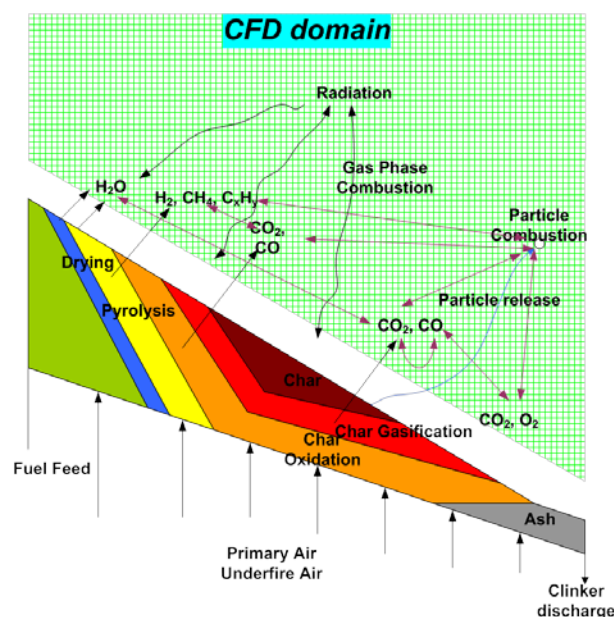


Figure 1. Schematic overview of the procedure for CFD modeling of solid fuel combustion in grate-firing units.

The devolatilisation of the fuel and partial oxidation of the volatiles in the bed, generated during devolatilisation, has been coupled with the combustion of gaseous species in the free-board and been applied with success in previous studies [3, 4].

Results from this study

In this study the gas temperature and the gas concentration profiles of O_2 , H_2O , CO , CO_2 , CH_4 , C_2H_2 , C_2H_4 , NH_3 and HCN along the waste bed at a distance of approximately 0.5m, depending on the bed thickness, were measured. Over a span of three days the gas composition and temperatures above the bed from combustion of municipal solid waste (MSW) were measured. All measurements were performed at Affald+, a Waste-to-Energy (W-t-E) plant located in Næstved, Denmark. The W-t-E plant has a nominal waste capacity of 8.2t/h. The plant uses the Dynagrate® grate technology. The grate is a single-lane grate, with dimensions 10.6x4m. The grate has been split into four zones with lengths of 2.8, 2.7, 2.7 and 1.8 meter, respectively. Predefined fractions of the primary air can be distributed to each zone.

The gas temperatures and concentration profiles of the major species above the fuel bed in combustion of waste at a grate-fired W-t-E plant were measured for two different plant operations to evaluate the effect of primary air distribution on the concentration profile of combustibles, water, CO_2 and NO_x precursors. The change in operating conditions involved a change in the distribution of the primary combustion air under the grate. The changes in primary air distribution involved only sections 2 and 3 on the grate. The fractions of air on grate 1 and 4 were unchanged as grate 1 acts to dry the waste and grate 4 mainly serves as ash transport; full conversion of the waste has occurred on the previous 3 sections.

The species concentration profiles were determined by gas extraction using a 6m water cooled probe, through a hole in the front roof of the combustion chamber, FTIR spectroscopy and spectral analysis using an in-house software at the Technical University of Denmark. The gas temperatures were determined by suction pyrometer attached on the water cooled probe. The measuring system allowed for concurrent UV, IR, O_2 and temperature measurements. The probe was manually inserted into the furnace at a defined angle and distance. The species concentrations and gas temperature were measured at four predefined locations in the furnace close to the fuel bed

The gas temperature increased from 800°C at the initial part of the grate to a maximum value of 1200°C about halfway down the grate, with the position depending slightly on the primary air distribution. As a fraction of the primary air is moved from the first to the second half of the grate a slight shift in the position of the peak temperature was measured, corresponding to a shift in the position of char oxidation on the grate. By use of visual inspection of the bed temperature using an IR camera the position of char oxidation on the grate was easily identified.

The major combustible gasses, after partial oxidation in the fuel bed, were determined to be CO , CH_4 and C_2H_4 with a maximum concentration of approximately 15vol%, 5vol% and 4vol% respectively. These species are only found above the first half of the 10 meter long

grate. A peak in the CO, CH₄ and C₂H₄ concentrations were measured after approximately 40% of total grate length. The partially oxidized devolatilisation gas mainly consists of CO. Smaller amounts of C₂H₂ were measured above the bed. Initially in the combustion process the concentration is negligible compared to the CH₄ and C₂H₄ concentration. However, at the end of process the C₂H₂ concentration exceeds that of C₂H₄. The larger C₂H₂ concentration is expected since it is an intermediate product of oxidation of higher hydrocarbons.

It was determined that during grate-fired MSW combustion the majority of the NO_x precursors are released as NH₃; more than 80%, while less than 20% are released as HCN, with a maximum precursor concentration measured to 10000ppm on the front part of the grate (figure 2).

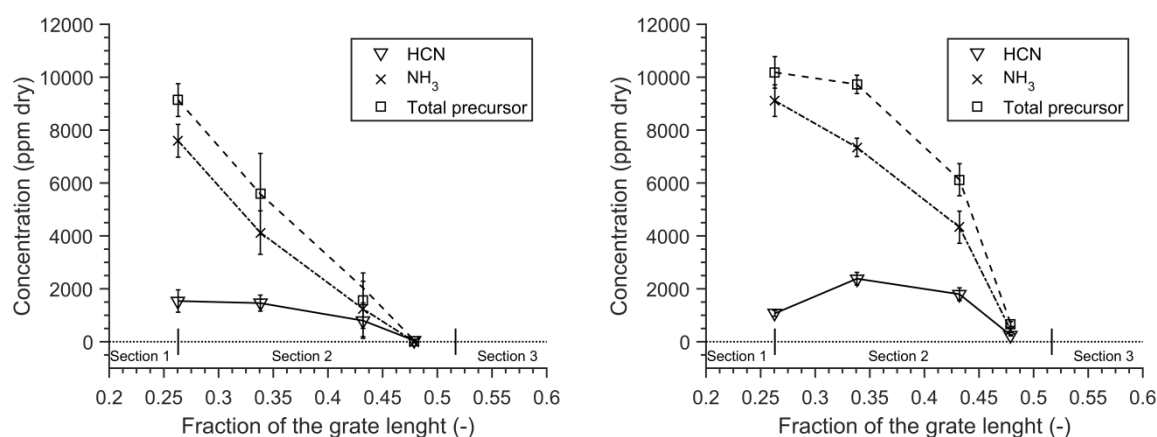


Figure 2. The concentration profiles of the major NO_x precursors during combustion of MSW as a function of the grate length during plant operation 1 (left) and plant operation 1 (right).

The influence of NO_x precursor composition, the distribution between NH₃ and HCN, on the NO_x formation was examined through simulations in CHEMKIN by PSR calculations. The simulations were done using three different inlet gas compositions; a composition corresponding to what was measured in the W-t-E (80% NH₃ and 20% HCN), and compositions where all reactive N was NH₃ and HCN, respectively. The predicted formation of NO_x is shown in figure 3.

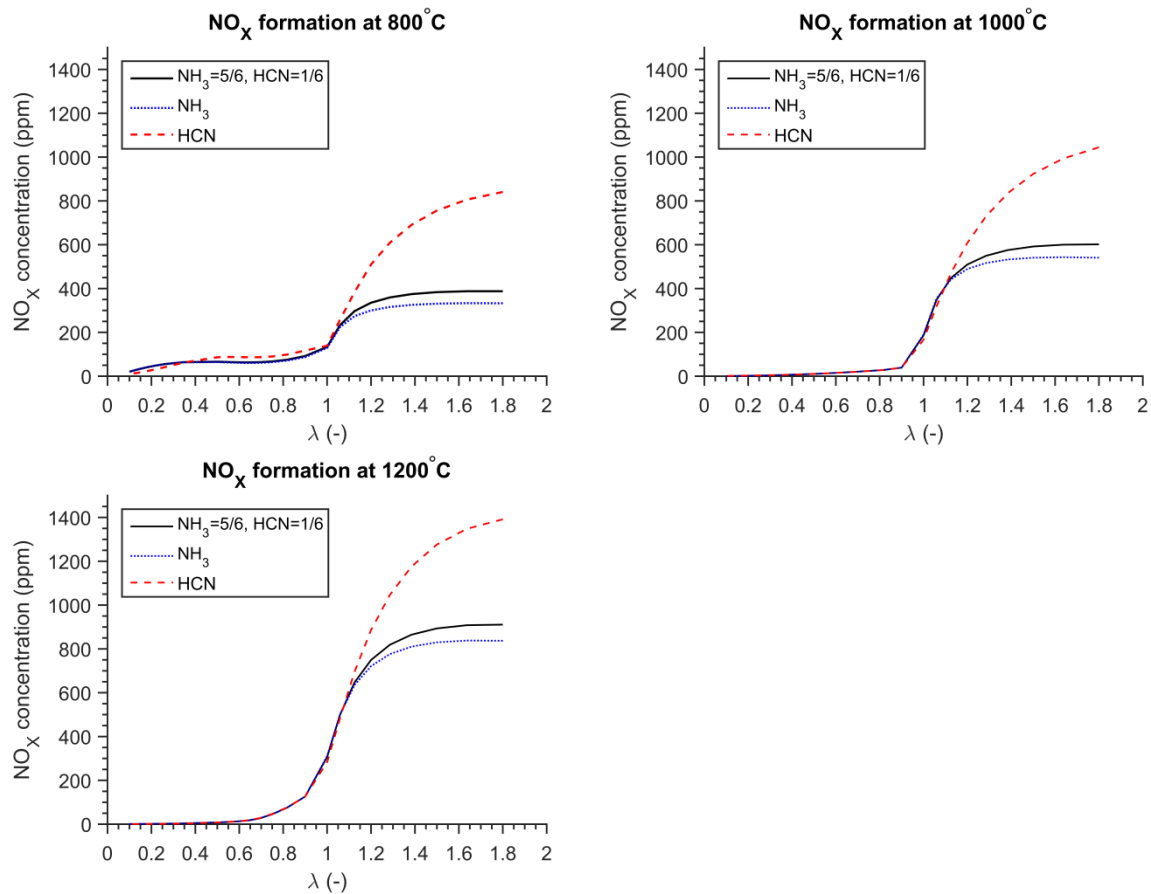


Figure 3. The influence of the precursor on the NO_x formation at $T=800, 1000$ and 1200°C for increasing λ . The pressure is 1 atm and the nominal residence time is 1 s. The total precursor concentration was 10000ppm for all simulations. — $\text{NH}_3=9000\text{ppm}$ and $\text{HCN}=1000\text{ppm}$, --- $\text{NH}_3=10000\text{ppm}$ and $\text{HCN}=0\text{ppm}$, - - - $\text{NH}_3=0\text{ppm}$ and $\text{HCN}=10000\text{ppm}$.

As expected the NO concentration increases with increasing excess air ratio (λ) until a certain point where no more NO is generated and the gas is merely diluted by additional air. At values of λ below 1.1, the choice of precursor does not influence the final NO concentration in the temperature interval investigated. At high excess air ratios, the choice of precursor has a large impact on the predicted NO formation, with HCN oxidation yielding significantly higher levels of NO. At $\lambda=1.5$ the NO_x concentrations found from the PSR simulation are 128, 71 and 54% higher when HCN is used as precursor, compare to NH_3 , for temperatures of 800, 1000 and 1200°C , respectively

For reliable modelling of the NO formation at high excess air ratios, $\lambda > 1.1$, it is important to determine the correct ratio between NH_3 and HCN, due to the different reaction sequence of hydrogen cyanide with a higher selectivity towards NO[1]. Below $\lambda=1.1$ the NO formation is roughly independent of the precursor speciation.

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